

# **Flight Test Experiments Foreseen for USV**

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Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE <b>01 JUN 2007</b>		2. REPORT TYPE <b>N/A</b>		3. DATES COVERED <b>-</b>	
4. TITLE AND SUBTITLE <b>Flight Test Experiments Foreseen for USV</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>CIRA, Head Space Programs USV Program Manager Via Maiorise 81043 Capua, Italy</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release, distribution unlimited</b>					
13. SUPPLEMENTARY NOTES <b>See also ADM002057., The original document contains color images.</b>					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>UU</b>	18. NUMBER OF PAGES <b>38</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

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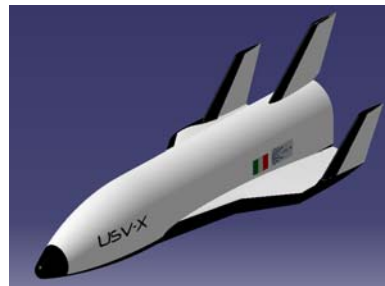
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## 1. OBJECTIVES AND FUNDAMENTAL CONCEPTS

### Objectives

The **Strategic Target** of the USV Program is the development of a **multi-purpose flying test-bed for “advanced” atmospheric re-entry** from a circular LEO at about 200 km

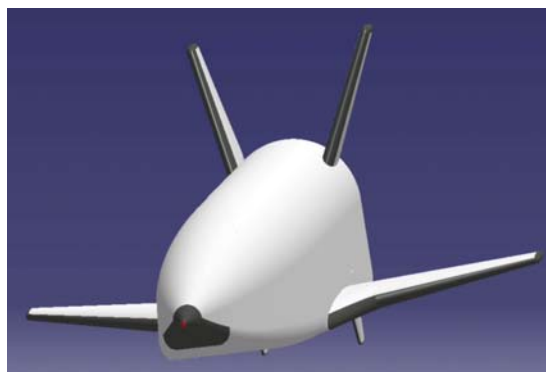
The technological developments associated to this target are **focused on the evolution of space transportation systems, oriented towards the aerospaceplane (SSTO-HTHL)**, believed to be sooner or later the future generation system concept.



### Flying Test Bed Concept

The qualifying character of the USV vehicles is the behavior of **Flying Laboratory** useful for reentry experiments ranging from sub- to trans, to low supersonic and to hot hypersonic flight → i.e. not just a vehicle flying one specific trajectory, but a *laboratory with the capability to fly different trajectories inside a flight operating envelope*.

The final aim is to offer to the scientific and industrial community the **opportunity to test and flight qualify** those technologies that are considered to be **enabling** towards the development of future generations reusable launcher.



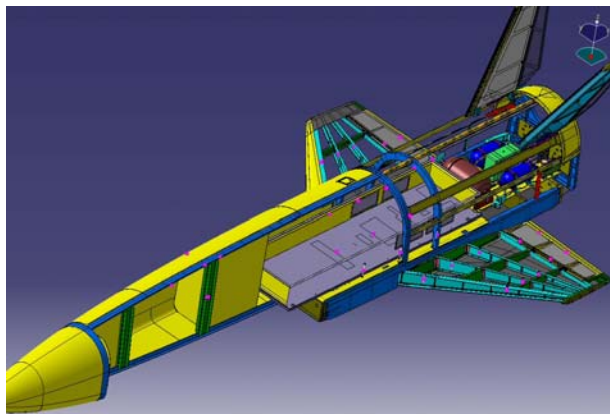
FTBs are designed taking into account the following fundamental requirements:

- ✓ High **maneuvering and control capabilities**, guaranteed by a proper aerodynamic configuration and advanced guidance and control system
- ✓ High **configuration and mission flexibility**, through the interchangeability and reconfiguration of the sensors system and parts of the vehicle (i.e. nose and wing leading edge)
- ✓ **Maximum commonality** between the aerostructural configurations and the on-board systems of the FTBs
- ✓ **Re-flyability** of the FTBs, in order to guarantee the realization of different experimental missions (at least 5)
- ✓ Possibility to host a “**payload**” (mass  $\leq 50$  kg)

### Experimentation Logic

The architecture is such that each FTB can provide 3 different levels or kinds of experimental capability:

1. The **Vehicle Itself** and its flight is an experiment
2. Aerodynamic, structural and other kind of **Distributed Sensors** are installed on board selected on a flight-by-flight base; they represent a specific experimental characteristic available for the community
3. A 0.1 m<sup>3</sup> space is reserved for a P/L with a max mass of 50 kg. Some power as well as some data handling capability are also offered (**Passenger Experiments**)

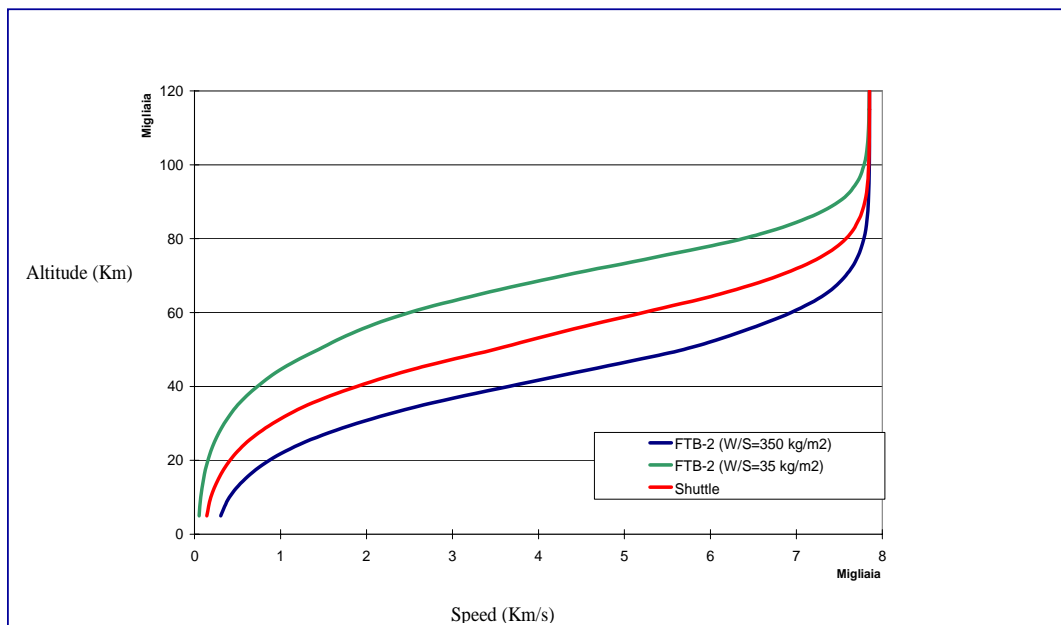


## "Advanced" Re-entry Concept

Performance requirements have to be incremental, and have to guarantee advancement with respect to Shuttle. The following targets are defined.

<b>Departure orbit:</b>	Circular at $\cong 200$ km	
<b>Configuration:</b>	Winged vehicle	
<b>Performances:</b>	$L/D_{USV} > L/D_{Shuttle}$	$E \cong 2.5$
	$[\alpha_{USV} < \alpha_{Shuttle}]$	$[\alpha < 30^\circ]$
	$(W/Sr)_{USV} \leq (W/Sr)_{Shuttle}$	$W/Sr \cong 100$ kg/m <sup>2</sup>
	High thermal loads	$T_w \cong 2300$ K
	Long re-entry time	1-3 hours
	Manoeuvre and control capability	
	Hypersonic horizontal flight capability	

The wing load parametric dependence is illustrated in the following figure.



The following consideration hold:

- Improved lifting re-entry space transportation vehicles is demanding for future routine access to space (e.g. space exploration, space tourism, etc.).
- Gliding and concept needs a step forward in R&T and system design approach wrt state-of-the-art (Shuttle)
- A broad and adaptive flight capability has to be guaranteed by future Flying Test Beds, in order to fit in-flight experimental requirements all along the re-entry pattern (rarefied, high enthalpy hypersonic)
- General characteristics:
  - ✓ manoeuvre and control capacity right from the initial phases of entry into the atmosphere;
  - ✓ flight corridor wide enough to follow various flight trajectories for experimental purposes;

The major technical criticalities can be summarized as follows:

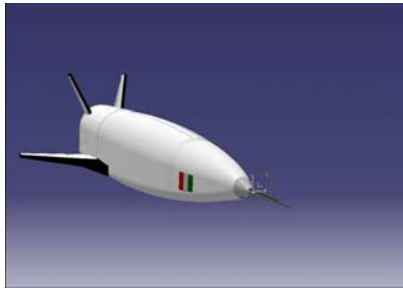
- fast and wide range changes of all flight parameters      necessity of robust guide and control systems
- necessity to assure stability and maneuverability conditions in all flight regimes (hypersonic, supersonic, transonic)
- exposure to very high energetic levels (25 MJ/kg) for long time (wrt Shuttle)  
necessity to use high performance thermo-mechanical hot materials and structures, well beyond the state of art
- aerothermodynamic effects not accurately predictable with the current numerical and experimental simulation capabilities

## **2. EXPERIMENTAL MISSION CLASSES**

System and technology targets are grouped in two **mission classes** following a complexity criterion related to flight regimes, technologies and launch systems:

### ATMOSPHERIC FLIGHT MISSIONS

- **DTFT**, Dropped Transonic Flight Test, maximum Mach in the range [0.8÷1.4]; three missions
- **DSFT**, Dropped Supersonic Flight Test, maximum Mach in the range [1.8÷2]; one mission



<b>Mach:</b>	$0 \div 2$
<b>Reynolds:</b>	$10^6 \div 10^7$
<b>Knudsen:</b>	$\cong 0$
<b>Total Enthalpy:</b>	$\cong 0$ MJ/kg

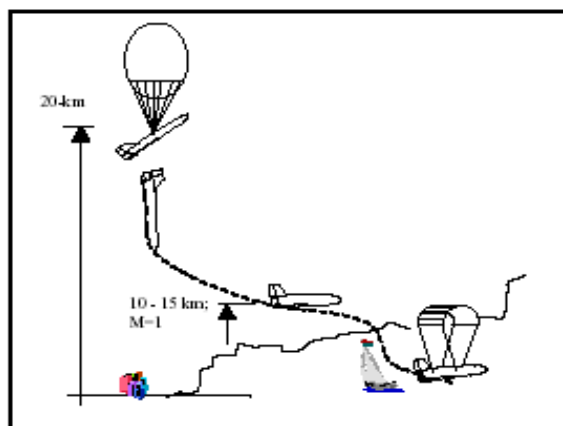
## Typical DTFT Mission

Dropped Transonic Flight Test (DTFT) - The balloon achieves an altitude of about 24 km, then the FTB\_1 vehicle is dropped. Between 10 and 15-km the vehicle has to cope with transonic aerodynamics conditions.

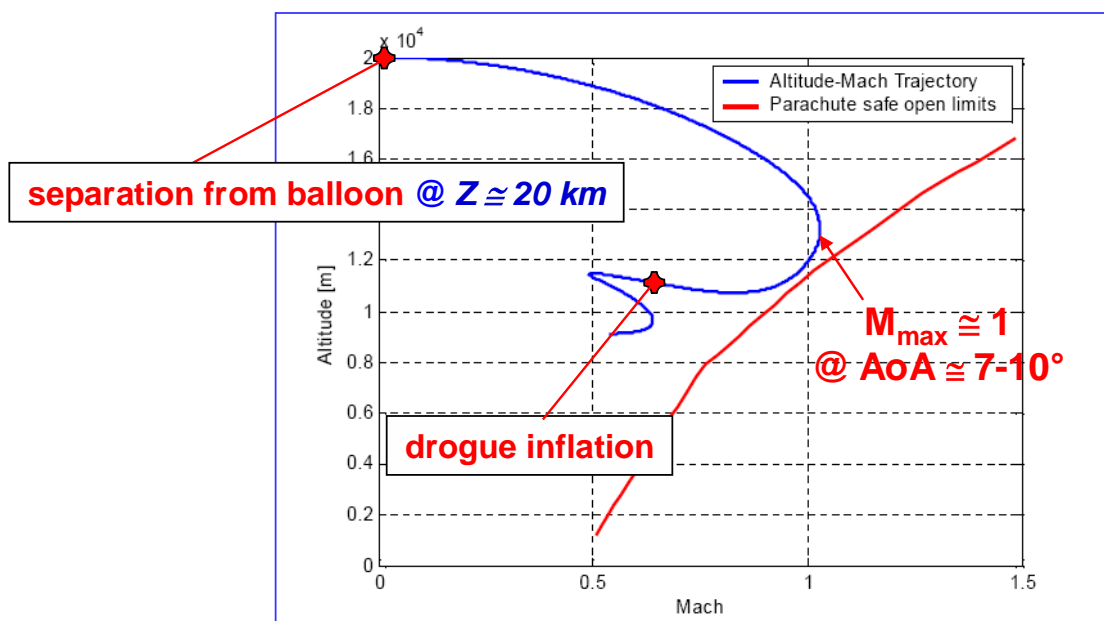
The main objective of this test is to have operative and technical confidence on particular aspects as

- Separation from balloon and maneuvers during the first few seconds of the mission
- Capability to support and manage the transonic conditions
- Correlation of analytical results of flight mechanics on stability, maneuverability, controllability.
- Capability to cope with the recovery phase (parachute deployment, capability to foresee and achieve the landing zone, ....).

The following figures show these requirements with respect to the expected performances.

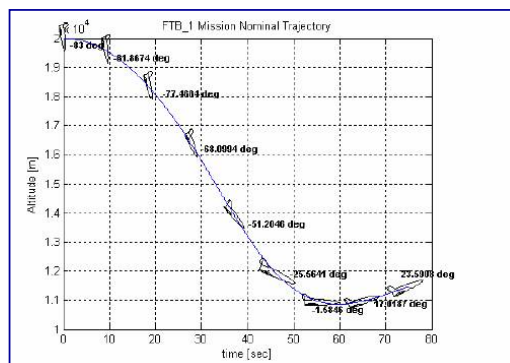
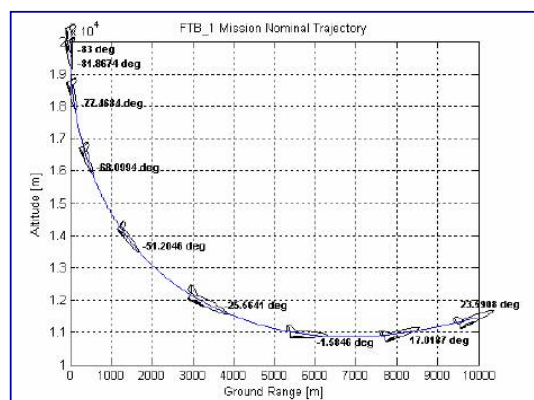
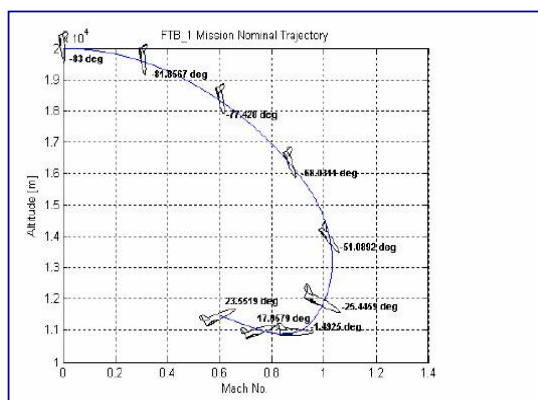






## First DTFT Nominal Trajectory

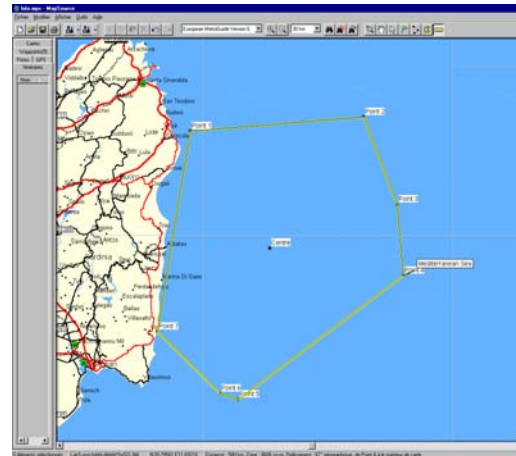
The actual designed nominal First DTFT mission is defined and illustrated by the data reported in the graphs below.



## DTFT/DSFT Mission Profile

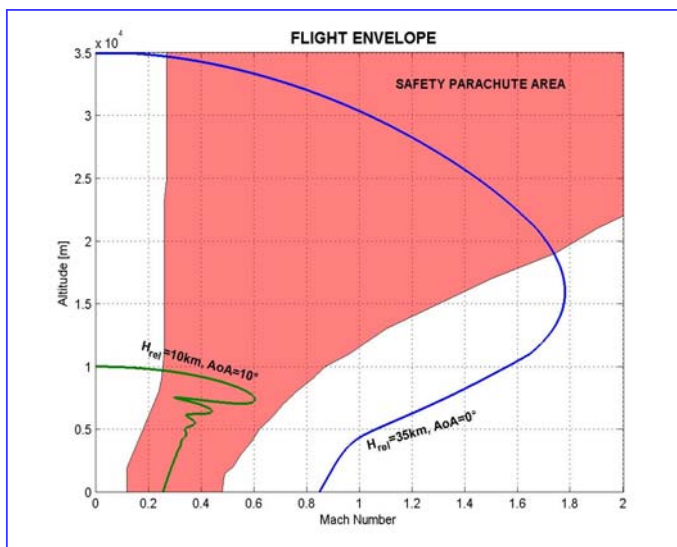
The mission profile is composed by the following steps:

1. Launch
2. Ascent (vehicle plus carrier)
3. Vehicle releasing
4. Autonomous flight
5. Deceleration (parachute opening)
6. Sea splash-down
7. Sea-recovery



*Mission Safety Area*

Four missions are foreseen: three in the sub-transonic regime and one in the supersonic regime, with the operating envelope shown in the following figure.



- Wide releasing altitude range (from 10km up to 35km)
- Maximum Mach number can be about 1.8 (without auxiliary booster)

This allows different flight profiles with different Mach and altitude in order to fulfil several mission requirements and experiments needs, in accordance with **flexibility** use of the flying laboratory.

The only constraint is imposed by the parachute opening safety area.

## RE-ENTRY FLIGHT MISSIONS

The second class of mission is directly related to reentry technologies. It consists of:

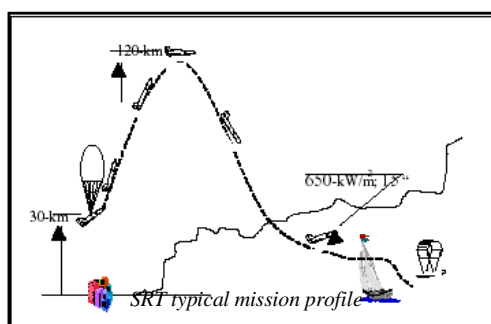
- Intermediate missions **like Sub-orbital Reentry Test (SRT)**
- **ORT**, Orbital Reentry Test

<b>Mach:</b>	$0 \div 25$
<b>Reynolds:</b>	$10^3 \div 10^7$
<b>Knudsen:</b>	$0 \div 10^3$
<b>Total Enthalpy:</b>	$5 \div 25 \text{ MJ/Kg}$



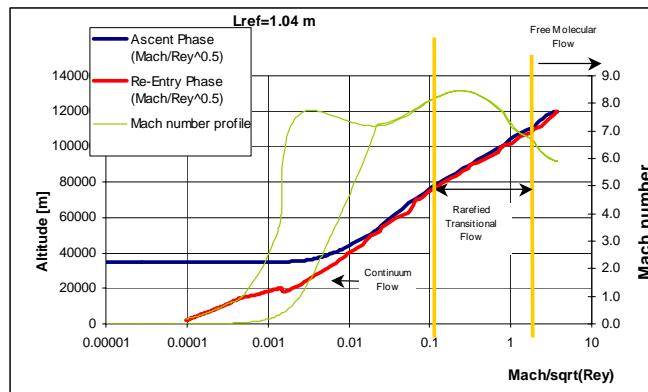
### Typical SRT Mission

The balloon achieves a floating altitude of about 30 km; after the release from the balloon a solid booster motor pushes the FTB vehicle in sub-orbital condition, up to an altitude of about 120 km. Then the vehicle starts the re-entry phase whose trajectory is optimized to maximize the heat load; thus, the vehicle achieves the maximum heat flux at about 25 km and keep a heat flux higher than 650 kW/m<sup>2</sup> for about 15 sec. Under the assumption of radiation equilibrium wall conditions, it is expected that the wall temperature will exceed 2000°C on both the nose and wing leading edge stagnation points.



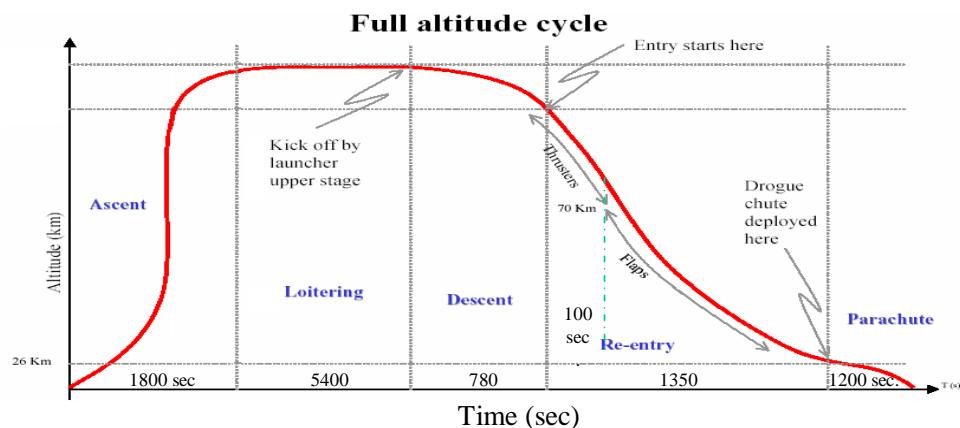
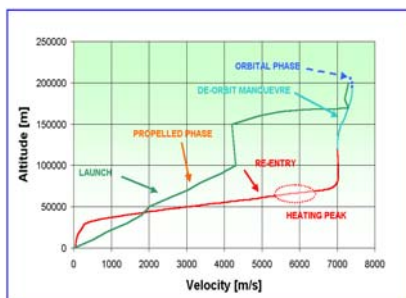
The main objectives of this test are:

- To have operative and technical confidence on re-entry aspects
- To provide research community with a Flying Test Bed able to test advanced materials under very severe conditions (more than 650 kW/m<sup>2</sup> for 15 sec); as the nose and the leading edge of the vehicle can be removed and replaced with other noses, depending on the radius at the stagnation point, it is possible to experience several levels of maximum temperature.



## Typical ORT Mission

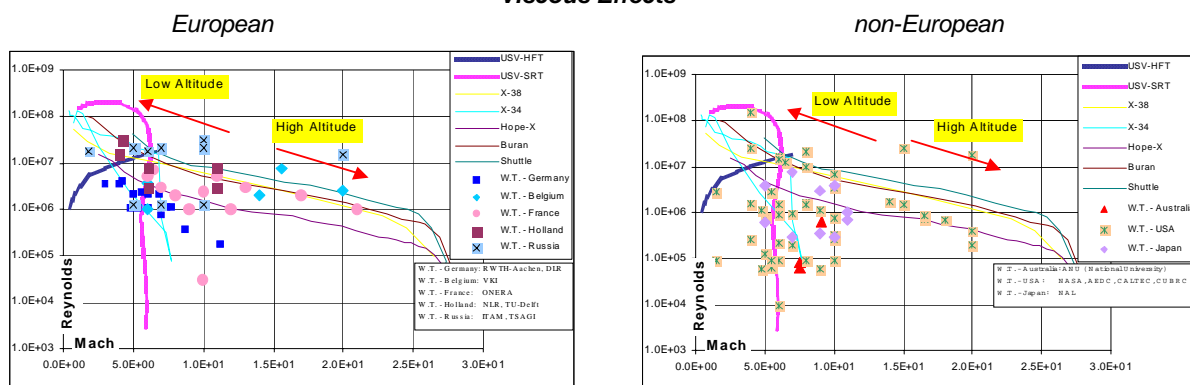
Orbital Reentry Test (ORT) - The final USV mission will be launched from the ESA-GSC in Kourou by the ESA small launcher VEGA. The FTB\_X vehicle will be inserted in a 200 km circular orbit remaining attached to the AVUM upper stage of VEGA. After one or two orbits, the de-orbiting will be executed by the AVUM, and the system will be put on an advanced reentry trajectory. Thanks to the proper combination of geometrical configuration (nose and wing leading edge radii) and reentry trajectory, the FTB\_X vehicle will experience heat fluxes of about 1300 kW/m<sup>2</sup> and wall temperature around 2000°C.



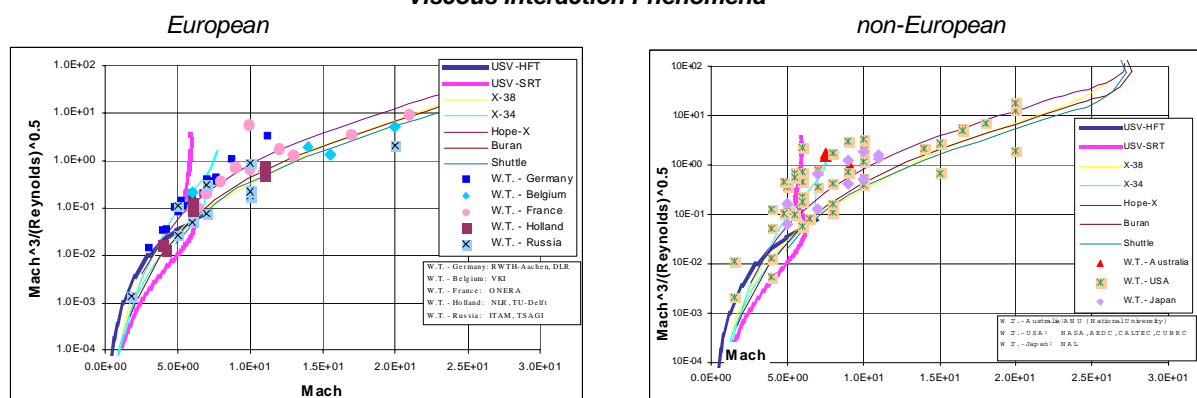
## Flying Test Beds Potentialities

Specific technologies embedded into the USV vehicles design will include high speed aerothermodynamics, advanced thermal protection system and autonomous flight operations. For what concerns aerodynamics, for example, it is stressed that USV offers the important capability to duplicate in flight a number of physical parameters typical of real launchers and reentry vehicles. On the other hand, it also duplicate what can be reproduced in a number of ground wind tunnel facilities, thus assuring the possibility to experimentally validate any extrapolation-to-flight correlation procedure. This is clearly shown by the following figures.

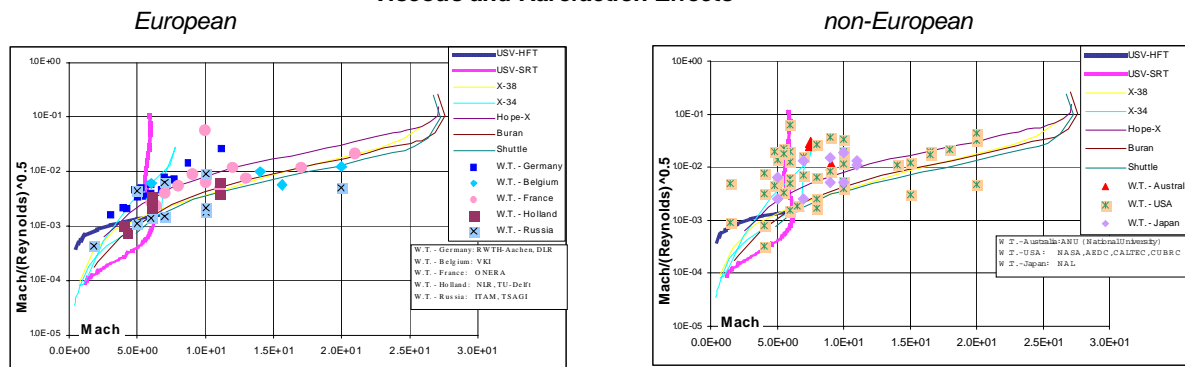
Comparison of USV with respect to other Re-entry Programs and Wind Tunnels  
**Viscous Effects**



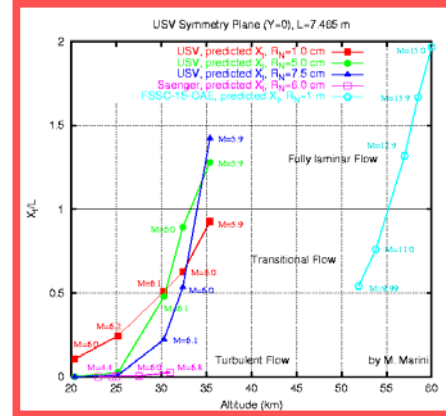
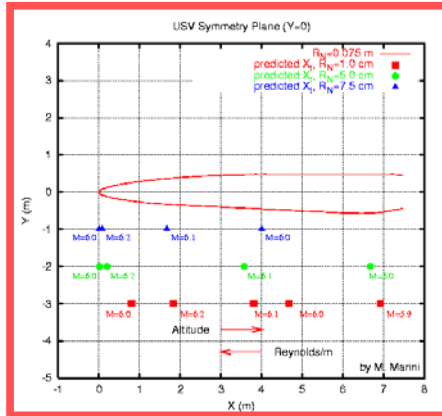
**Viscous Interaction Phenomena**



**Viscous and Rarefaction Effects**



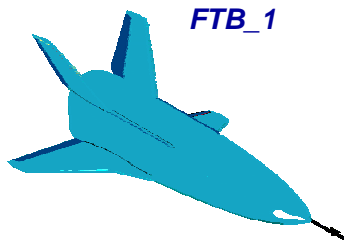
FTB represent also very good tools to flight testing the laminar-turbulent transition phenomenon. It is matter of fact that the predictable natural transition point calculated on the vehicle fuselage while flying the SRT trajectory moves widely along the fuselage itself .



Removable wing leading edge and nose-cone will allow to test different high temperature materials; the actual mission profile and shape definition are, in fact, designed to expose these components to heat fluxes exceeding 650 kW/m<sup>2</sup>, (significantly higher than the today spacecraft) for a significant period of time.

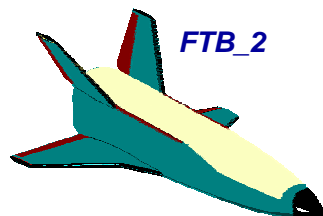
### 3. FLYING TEST BEDS (LABORATORIES) & EXPERIMENTS

In its original configuration, PRORA USV contained three FTBs whose objectives are given in the figure.



**FTB\_1**

- Transonic Flight,
- Max Mach = 1,
- Launched by Stratospheric Balloon



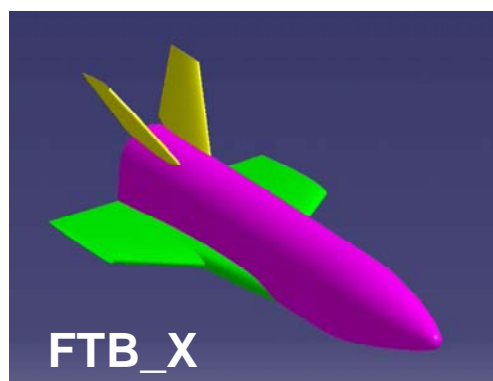
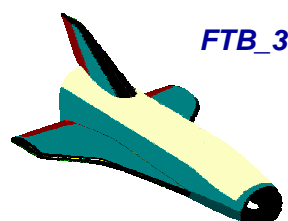
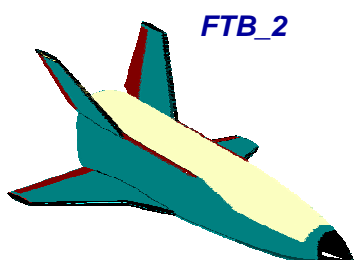
**FTB\_2**

- Horizontal hypersonic flight and sub-orbital reentry,
- Max Mach = 7,
- Launched by a rockoon (stratospheric balloon + booster)



- Orbital reentry, max Mach = 27,
- Launched by small launcher (Vega)

In 2004 the program has been revised on the bases of the lessons learned, and aimed at a much emphasized focalization. The major consequence was a logical merging of FTB\_2 and FTB\_3 in a new vehicle tagged **FTB\_X**, able to fly sub-orbital reentry trajectories as well as orbital reentry once during which horizontal hypersonic conditions should be realized for an adequate period of time.



### FTB\_1 - Low Atmosphere, Low Speed

Two FTB\_1 units to be built. The first vehicle is in its **manufacturing and construction** phase. The **first flight** is planned during next winter (Jan '06) and launch will be executed by means of stratospheric balloon from Air Force polygon (PISQ) based in Sardinia.

Summer launches will take off from ASI Trapani Milo Base in Sicily

The Experimental Program consists of some summer and winter flights to be executed by the twin FTB\_1, alternatively.

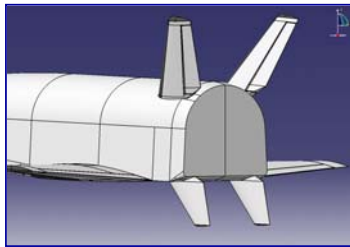




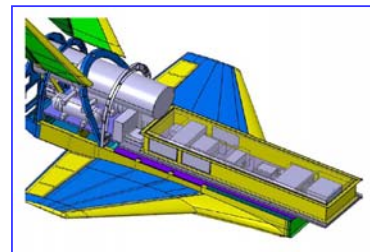
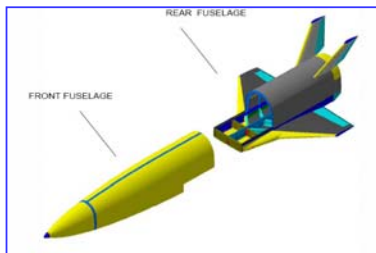
FTB\_1 represents an available national experimental lab able to offer typical conditions an RLV could encounter in low-supersonic, transonic and high subsonic regimes ( $0.3 < M < 1.4$  extendable to about 2). USV funded flights can host passenger experiments from other programs, and other flights of FTB\_1 could be considered for further experimentation on the bases of different trajectories to be properly designed and optimized.

The FTB\_1 configuration is based on the following driving elements:

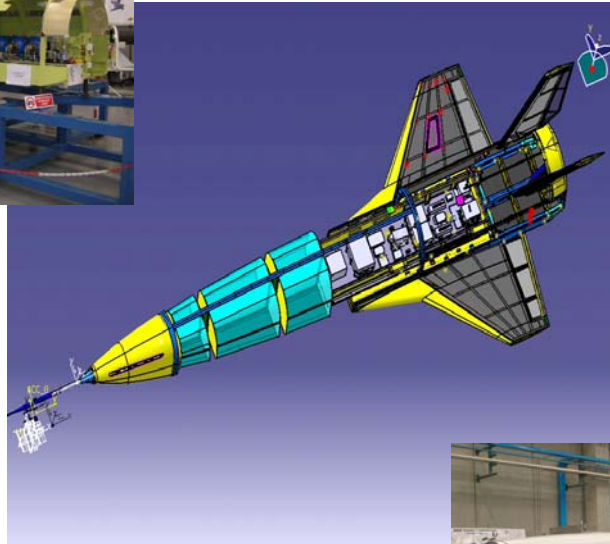
- aerodynamic efficiency  $L/D > 2.5$  from transonic to supersonic
- maximum thickness of wing profile: 8%
- nominal nose radius : 10 mm
- a four-vertical-fin configuration has been introduced in order to reduce interference with wing, with parachute at deployment, and structural constraints; as well as to match stability and control requirements



The structure (STR\_1) subsystem will ensure the structural integrity of the system as well as a suitable accommodation and mechanical interfacing of all the others subsystems. STR\_1 subsystem has been designed to resist water impact .







For what concerns the internal lay-out, the sub-systems are:

- Guidance, Navigation and Control (GN&C1)
- On Board Data Handling (OBDH1)
- Telemetry, Tracking and Command (TT&C1)
- Electrical Power System (EPS\_1)
- On Board Data Acquisition (OBDA1)
- Thermal Control System (TCS\_1)
- Hydraulic System (HYSY1)
- Recovery System (RESY1)
- Passenger Experiments (PEX\_1)
- Harness (HARN1)
- On Board Software (OBSW1)



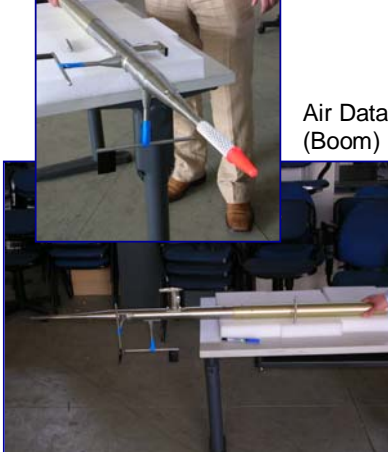
RF Power Amplifier

Fig. 9 RF Power Amplifier

INS sensor



Air Data System  
(Boom)



## Key Transmitter Features

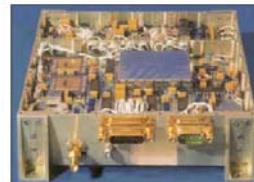
- BPSK/QPSK modulation schemes selectable via the TT&C
- Data rates from 9.6 kbps to 8 Mbps, choice of 2 selectable over the TT&C
- RF output power 150 mW, 400 mW option
- Dimensions: 190 x 135 x 22 mm
- Mass: 420g
- Power Supply: 5 V, 680 mA



Transmitter module

## Key Receiver Features

- Frequency: 2025 to 2110 MHz
- Modulation: PM carrier with command data BPSK modulated onto 8 or 16 kHz Subcarrier
- Data rates: 8 bps to 4 kbps
- Conform to CCSDS/ESA/NASA RF modulation standards
- RF input level: -40 to -124 dBm
- Dim.: 170 x 166 x 49 mm
- Mass: <1000 g
- Power: 2.9 W @ 28 V



Receiver module



Hydraulic System

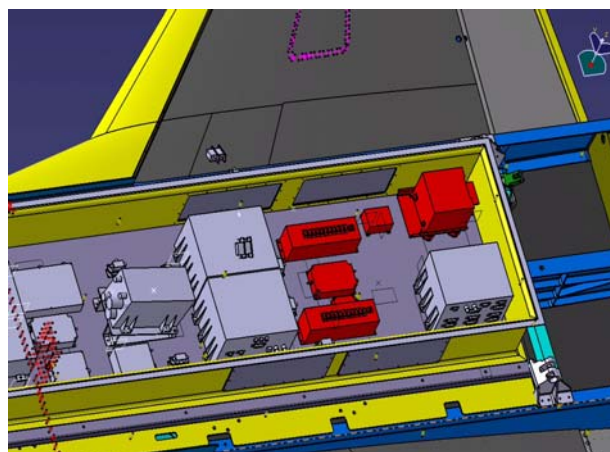


## Some Sub-systems

### Resources for Payload Experiments

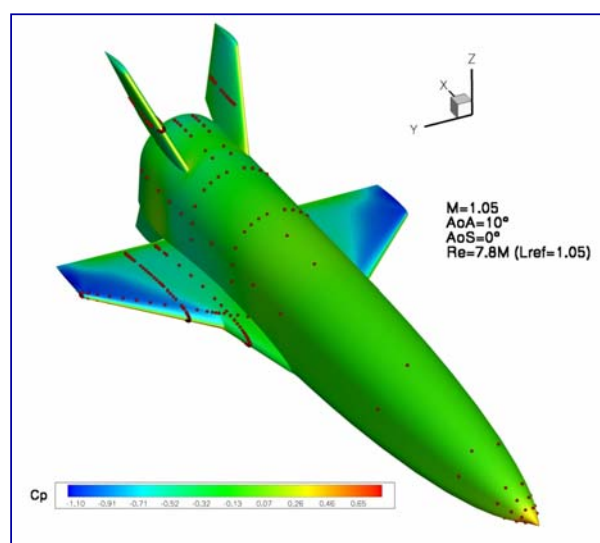
FTB\_1 as Flying Laboratory offers the international aerospace community possibility to investigate different fields of interest such as Aerodynamics, Structural Mechanics, Aeroelasticity, Flight Mechanics, and GN&C. It is capable of hosting on-board experimental payload (red boxes) and providing the needed resources in terms of:

- Mass accommodation: an experimental payload of 30 Kg inside the Avionic Bay and 20 Kg outside the Avionic Bay,
- Available volume: 650x377x180 mm<sup>3</sup> inside the Avionic Bay
- Power: 616 [W]
- Independent data link up to 1 Mbit/s



### Resources for Aerodynamic Experiments

300 x 0.8mm diameter pressure taps for investigation of vehicle-airflow interaction in a wide range of velocity regime (subsonic, transonic, low supersonic).



CFD simulation with pressure taps location

## Resources for Flight Mechanics:

Subsonic-supersonic Pitot-Boom featuring a wide range of measurements as angle-of-attack, side-slip angle, air static pressure and total temperature.

A Flash Air Data System could be implemented by replacing the Pitot-Boom, whose interface with the vehicle is a portion of the FTB\_1 nose.



INS – Inertia Navigation System



The Air Data System installed on the vehicle nose

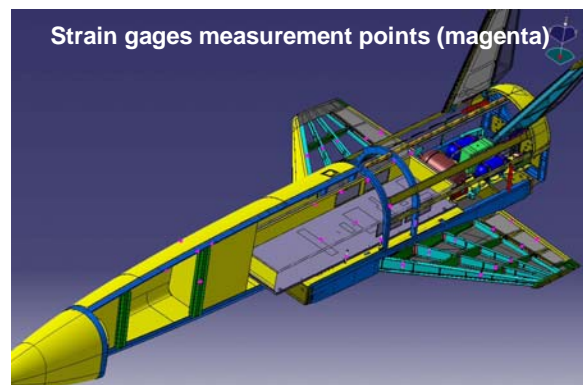


ADS – Air Data System

## Resources for Mechanical Behaviour:

150 strain-gauges to investigate the vehicle main structural items behavior undergoing the flight loads envelope. Objectives:

- validation of loads extraction methods
- verification of structural design methods.

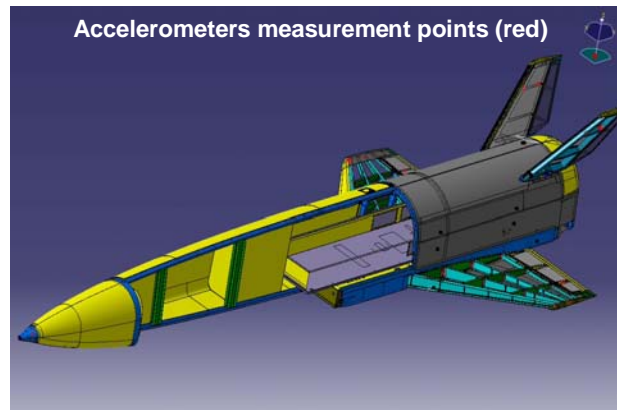




A set of twelve accelerometers embedded inside FTB\_1 wings to investigate aeroelasticity. Objective:

- validation of the aeroelastic model in transonic flight

It must be noted that FTB\_1 structural refurbish-ability as well as strain-gauges waterproof-ability can ensure the possibility to either embed a different sensors layout for a different investigation need or to repeat investigation in the same locations of interest.



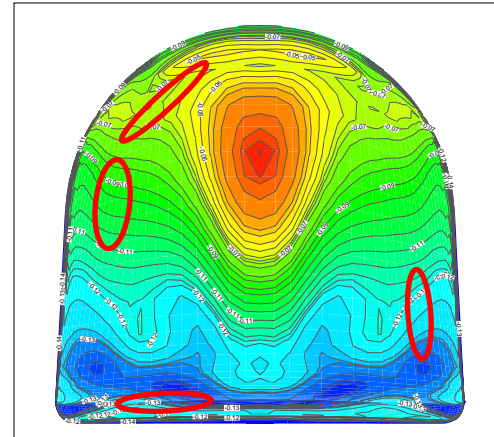
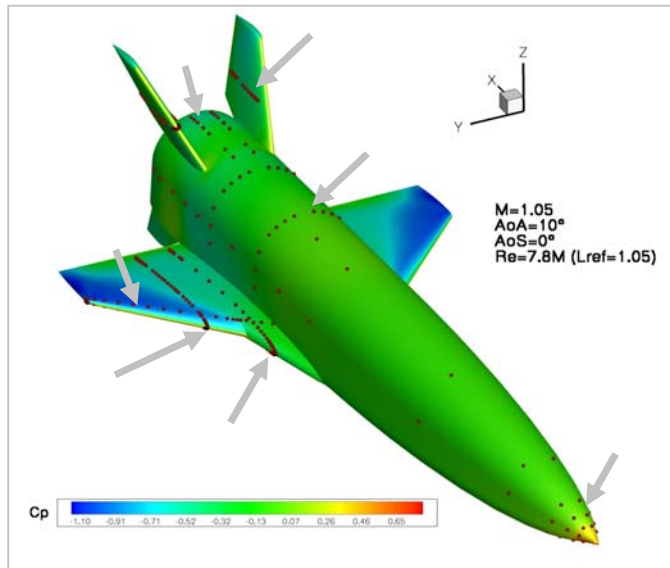
FTB\_1 multi-mission capability can also give chance to make that under several others loads envelopes.

### USV 1 Experiments in Aerodynamics

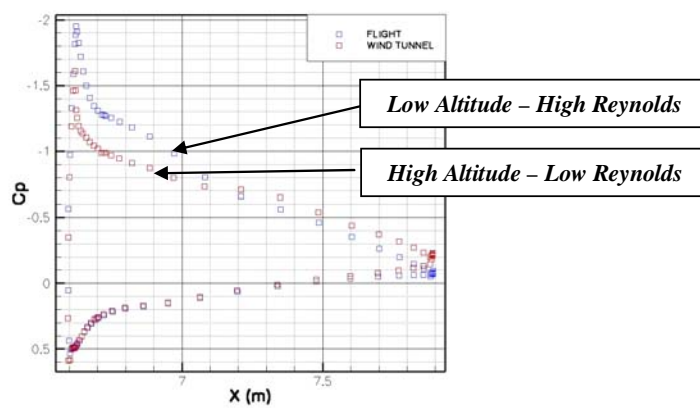
The reliability of the Aerodynamic Prevision Model (APM) generated for the USV Aero Data Base development will be checked through the comparison with in-flight data. In particular main benefits obtainable by gathering in-flight data may be recognized in the following items:

1. *Verification of predictive capabilities of Computational Fluid Dynamics (CFD) codes for a complex configuration in flight condition.*
  2. *Verification of the suitability of the Wind-Tunnel Test methodology.*
  3. *Verification and tuning of the methodology for the extrapolation to flight condition of the experimental measurements.*
  4. *Reduction of the uncertainties margin associated with the pre-flight prediction of the aerodynamic coefficient.*
- ❑ EXPERIMENT A: GLOBAL aerodynamics. Evaluating the difference prevision/flight measurements on global aerodynamics coefficients  $C_L$ ,  $C_D$ ,  $C_Y$  and on derived sizes  $L/D$ ,  $X_{cp}/L_{ref}$  in transonic/low supersonic regime.
  - ❑ EXPERIMENT B: LOCAL aerodynamics (pressure measurements). Evaluating the difference prevision/ flight on static pressure measurements in transonic/low supersonic regime in very interesting regions of the vehicle (from an aerodynamic point of view)

By means of CFD computations the most interesting regions of the body in terms of phenomenological complexity have been identified. Mainly the attention has been focused over zones with maximum pressure gradient and/or with large variation with respect to the flight regime (AoA, AoS, Mach).

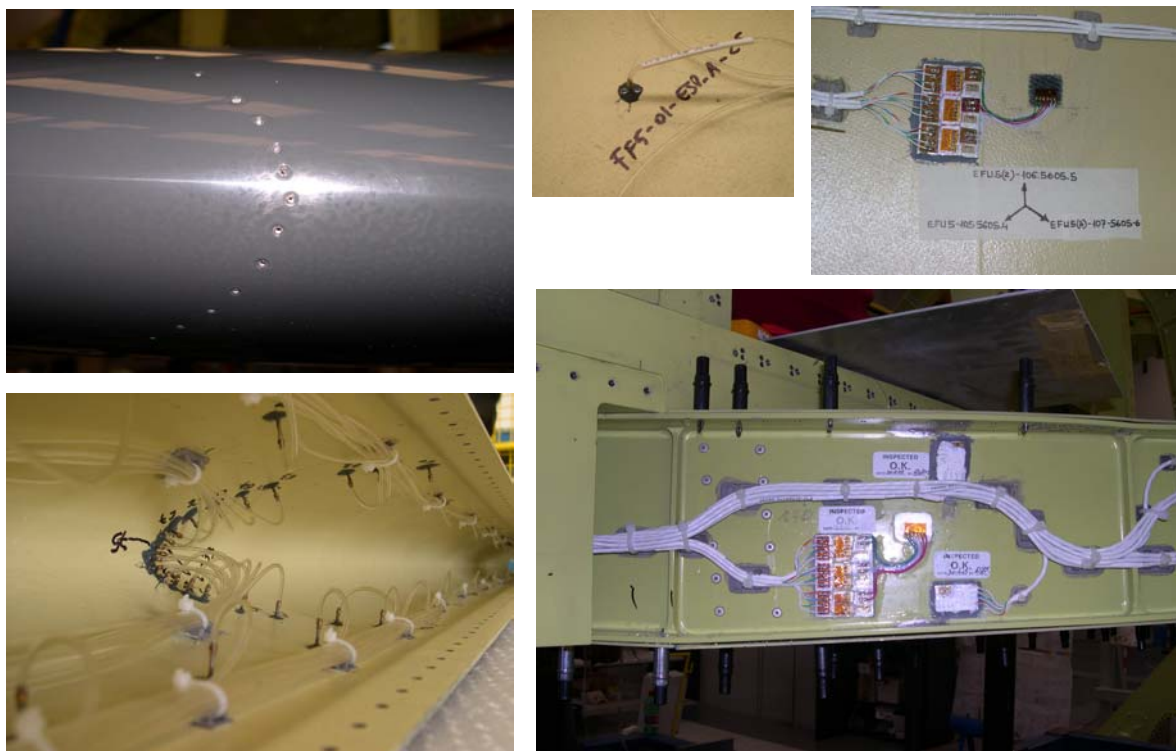


Base Plate. Large separated region.



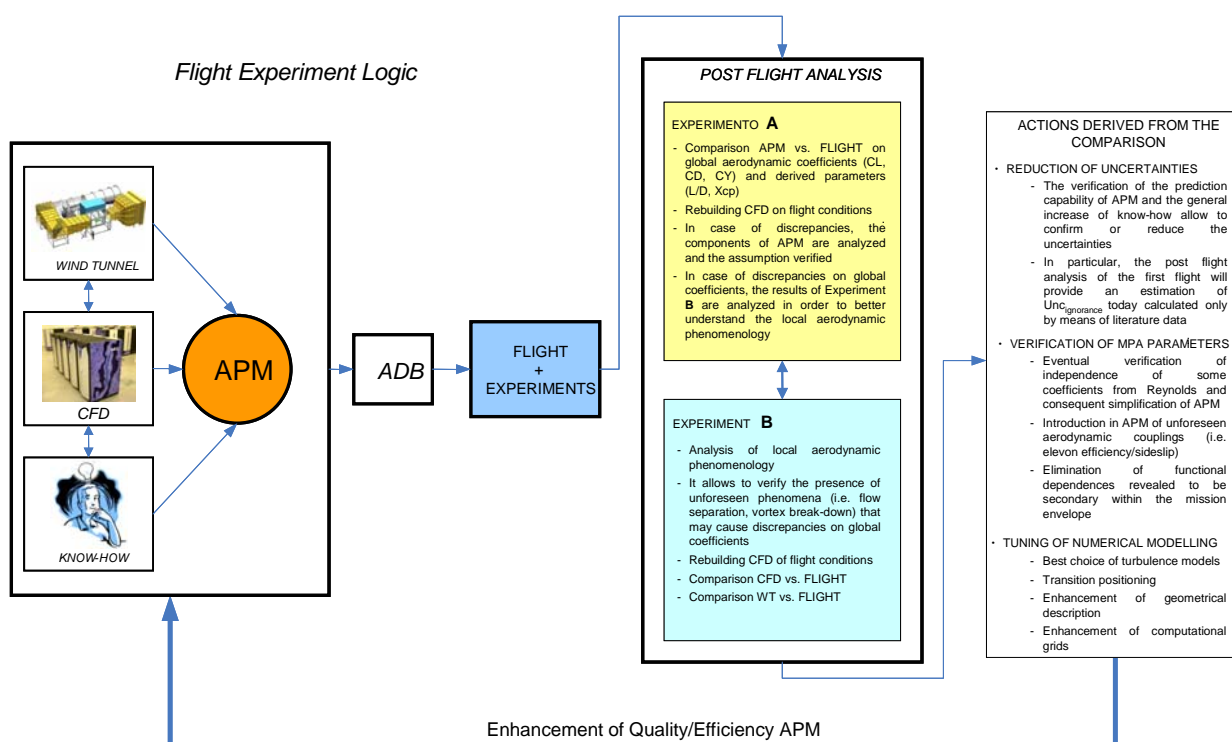
Front fuselage pressure taps

## Flight Test Experiments Foreseen for USV



Details of USV\_1 Aerodynamic Flight Experiments setup

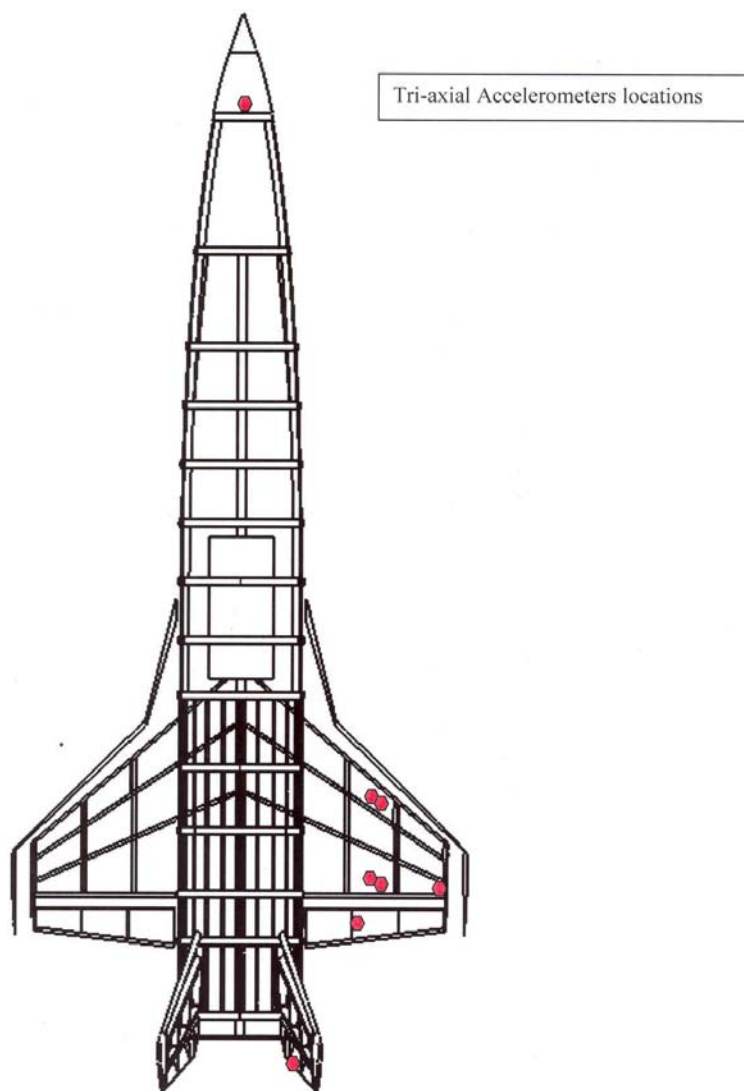
### Flight Experiment Logic



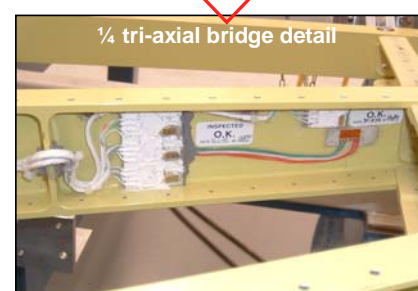
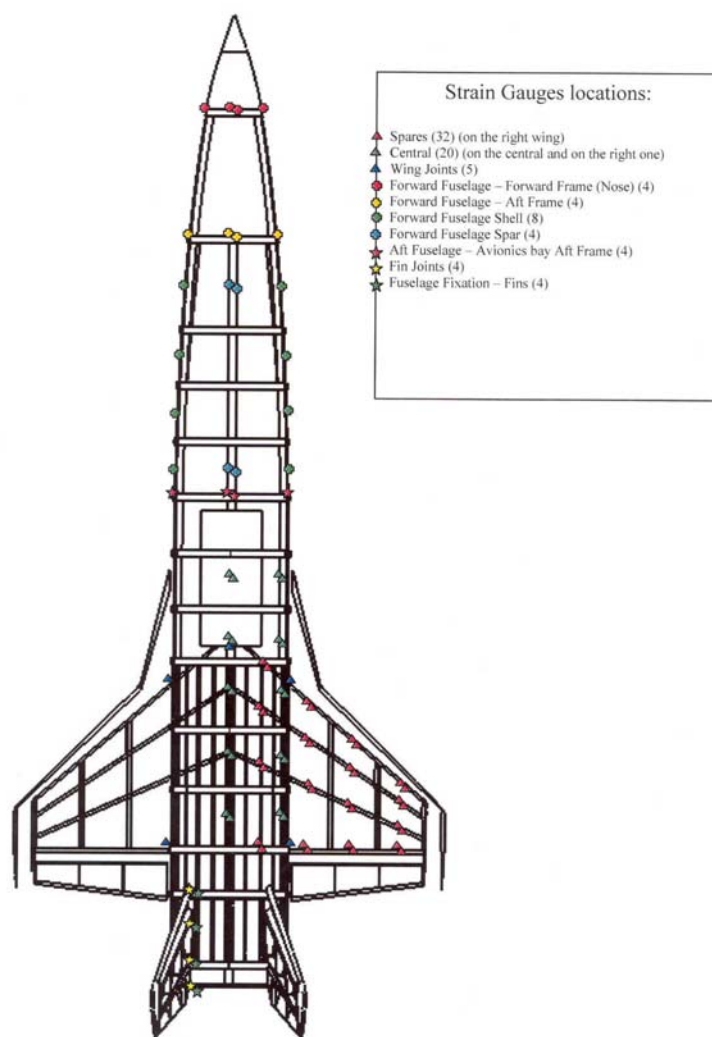
USV\_1 Experiment on Structures

- EXPERIMENT C: IN-FLIGHT LOADS EVALUATION by means of strain-gage technique activities description

The aerodynamic and inertial loads will be evaluated using assumption of liner relationships between the direct strain gage measurements (strain) and the external loads (shear and moments). A set of strain-gages has been installed on the vehicle in strategic positions reaching two goals: *strain – external loads* simply correlation and stress levels evaluations. A static calibration test has been performed in order to evaluate *strain – load* transfer functions. Experimental correlation has been performed in order to validate the FEM structural model;



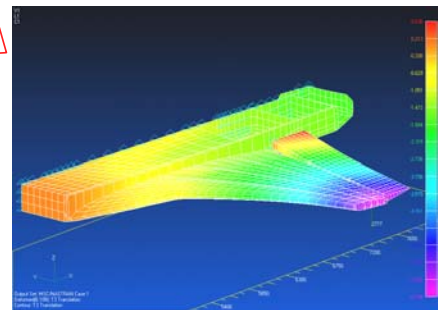
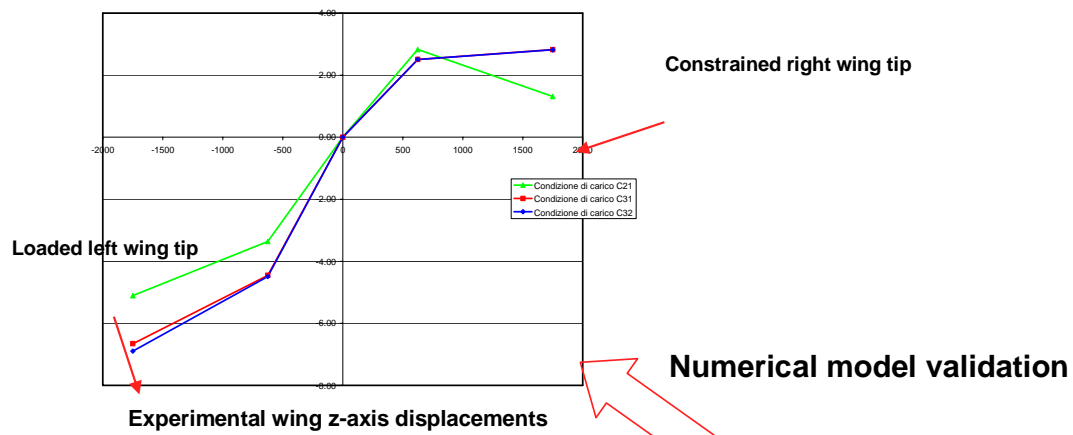




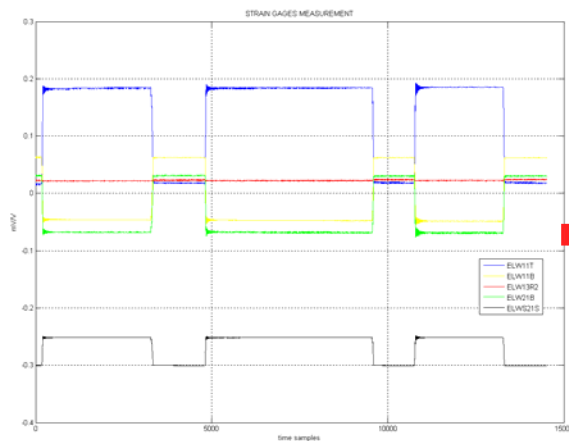
Experimental Setup



## EXPECTED RESULTS



Numerical wing z-axis displacements



Some strain-gage signals (mV/V) for load cycles.

Data post-processing

- Noise filtration
- Offset evaluation
- Mean strain evaluation
- *Strain – external load* transfer function calculation

### FTB\_X - Advanced Reentry

The second phase of the USV Program includes the realization of an advanced flying laboratory, tagged **FTB\_X**, able to perform a series of re-entry missions responding to a progressive complexity logic, from sub-orbital (SRT) up to a complete re-entry test from about 200 km LEO (ORT).

The ultimate goal is to achieve an **extended gliding re-entry capability** with very long down range (re-entry times up to 3 hours), through a slender and efficient aerodynamic configuration, advanced TPS materials, robust guidance navigation and control systems.

The detailed design will be targeted to have the Maiden Flight within 2010, launched by means of VEGA.



FTB\_X mission and system design is driven by in-flight testing requirements resulting from R&T needs defined by scientists in the field of future generation space transportation systems.

Primary envelope of in-flight testing capabilities of FTB\_X is defined for the following R&T areas, running in the frame of USV\_Tech program:

- ☐ Aerothermodynamics
- ☐ Structure and materials
- ☐ Guidance, navigation and control

Further experimental needs (optional) are collected from other R&T scientists, to accommodate passenger experiments of scientific, technological and industrial interest for both re-entry and orbital phase of the USV\_X mission.

### Mission Objectives

<b>Orbital Re-entry Test</b>  <b>ORT</b>	<p>Reference mission consisting in complete re-entry flight from Low Earth Orbit at 200 km</p> <p>Re-entry path characterised by moderate angle of attacks (less than <math>20^\circ</math>) and a longer flight duration (1÷3 hours), to allow for extended adaptability to in-flight testing capabilities under high energy hypersonic flight conditions</p>
<b>Sub-orbital Re-entry Test</b>  <b>SRT</b>	<p>Intermediate step for both design validation and risk mitigation purposes</p> <p>Mandatory requirements for the SRT mission to be eligible for such purposes are:</p> <ul style="list-style-type: none"> <li>➤ a minimum acceptable total enthalpy higher than 5 MJ/kg, to allow for aerothermodynamic non-equilibrium phenomena to occur;</li> <li>➤ aero-thermo-mechanic characteristics fully representative of those of the reference mission, in order to progressively validate in flight critical design aspects</li> </ul>

### Programmatic Requirements

<b>Project launch date</b>	Phase B to be launched within year 2006, after completion of the Phase A consolidation study aimed at delivering a consolidated baseline system configuration (vehicle, launch system and operation), the related design and development plan, as well as the USV_X project specifications
<b>First flight</b>	The first flight of the FTB_X vehicle shall be able to be performed before the end of 2010, assuming the above stated project launch date. In any case, the duration of the development phase, from phase B beginning up to phase D completion (FTB_X vehicle Acceptance Review), shall be targeted not to exceed 4-4.5 years
<b>Cost target</b>	<p>The cost for overall FTB_X system design development (Phases B, C and D) shall include:</p> <ul style="list-style-type: none"> <li>➤ two units of the vehicle</li> <li>➤ some peculiar payloads related to system design aspects, to be selected at the end of the consolidation study</li> </ul>
<b>RAMS</b>	<p>The probability of success of any FTB_X mission shall be higher than 0.93. This figure includes the recovery of the tested hardware and recorded data.</p> <p>The probability of loss of human life during the flight over populated areas (population flown-over) shall be <math>&lt; 10E-7</math>, according to the CSG-RS-10A-CN, iss 5/0 standard safety rules.</p>

## **Main Vehicle Design Requirements**

Efficient aero-thermodynamic wing-body configuration with the following target design parameters, to be verified at the end of the phase A consolidation study, shall be considered:

- ✓ a higher (L/D) ratio with respect to classical re-entry vehicle configurations, up to a maximum value of approximately 2.5 at Mach number in the range [8-10];
- ✓ a lower wing load ( $W/S_r$ ) with respect to classical re-entry vehicle configurations, down to 100 kg/m<sup>2</sup>.

The primary structure shall be designed to

- ❖ contribute to the wing load reductions toward the above defined design target figure (lightweight concept);
- ❖ allow for in-flight testing of novel hot structures concepts based on advanced UHTC materials at the level of either complete vehicle sub-assemblies, specifically the nose cap and wing leading edge, and material samples.

The Thermal Protection System shall:

- ❖ withstand the aero-thermal fluxes experienced during the atmospheric re-entry (25 MJ/KG), with the aim of preserving the overall vehicle integrity in both nominal and off nominal flight conditions as defined by the GNC capabilities;
- ❖ contemplate the use of hot structures based on high and ultra-high temperature massive ceramics on the mostly exposed parts of the vehicle (nose and wing leading edge);
- ❖ be designed and manufactured in order to maintain abrupt steps and gaps along the outer mould line within acceptable limits, to be defined, to avoid heat peaks.

The GN&C system shall be designed to:

- ❖ provide autonomous on-board attitude and flight control capabilities in the overall re-entry phase, either using a reaction control system or aerodynamic control surfaces;
- ❖ handle large aerodynamic uncertainties and a wide Mach number range, from hypersonic to low subsonic as well as a defined set of off-nominal conditions (robust design).

## **Operation Requirements**

The ORT reference mission shall be accomplished using the VEGA launcher, with the AVUM fourth stage to be used for orbit injection, orbiting and de-orbiting maneuvers, at least for the first re-entry mission.

As far as the SRT intermediate missions are concerned, a trade-off analysis shall be performed in phase A among the following launch options:

- ❖ VEGA launcher, using the AVUM system to drive and release the FTB\_X vehicle at the initial altitude and speed conditions as per mission requirements;
- ❖ low cost launcher, either commercial or provided through international cooperation agreements, with the main constraint that full compatibility with the VEGA launcher, in terms of vehicle size and interfaces, is guaranteed.

The vehicle shall be landed in the sea after a final parachuted descent phase. The location site shall be selected according to the following factors:

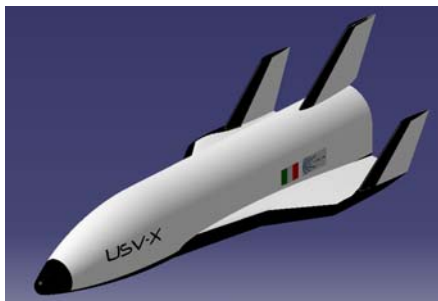
- ❖ minimum time of recovery of the vehicle, in any case lower than 48 hours (TBC);
- ❖ applicable aero-navigability regulations during the final descent and parachuted phase;
- ❖ existence of a logistic base to support the operations in the proximity of the recovery area.

Each unit of the FTB\_X vehicle shall be re-flyable for a target figure of 5 flights, either sub-orbital and orbital. After mission completion, the vehicle shall be made ready to operate in 12 months (TBC), after proper refurbishment and reconfiguration according to the successive mission requirements.

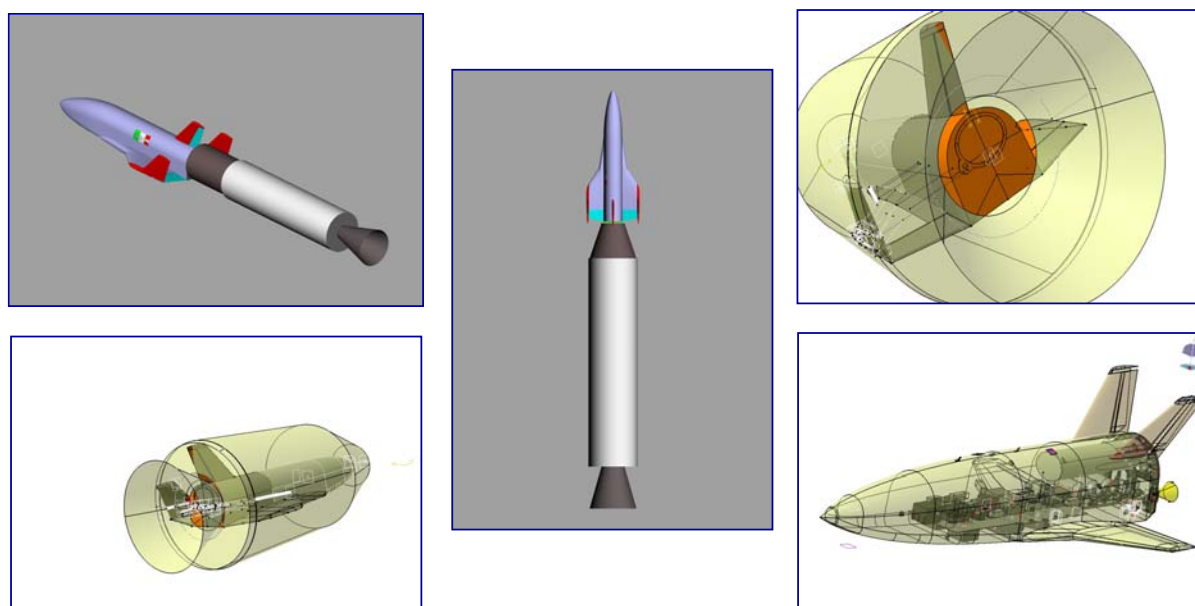
The ground segment shall be designed in order to comply with all the USV\_X mission operation requirements, from pre-flight up to post-flight phases. The ground segment shall then include all the ground communications and data handling infrastructures and operation procedures, with the exception of those provided by the launch base.



Concept derived from FTB\_1 design



Alternative concept for improved performance



## Proposed Experiments (examples)

### *a) Ceramic bolts nanostructured, Proposed by AAS-I*

- Ceramic bolts and nuts able to withstand the re-entry environment when directly exposed up to about 2300°C with a residual mechanical strength sufficient to assure the efficiency of the joint.
- Based on advanced ceramics mixed to carbon nanotubes treated in such a way to avoid all possible compatibility problems with the ceramic matrix.
- Nanoparticles under investigation: Nanoonions, Single Wall Nanotubes or Multi-Wall Nanotubes.
- At the end of the material characterization campaign the bolts material composition will be frozen and then the on-ground testing of the bolts will be performed, including testing at the extreme temperatures. Once completed the on ground demonstration, the fasteners will be cleared for flight use.

### *b) Active Cooling, Proposed by AAS-I*

- Metallic elements for leading edge-type applications cooled with an on-board fluid getting a light and robust design able to face all possible injures coming from the flight environment.
- New generation Ni-based alloy used in thin foils laser-welded to get an external flush surface and an internal cooling channels distribution able to cover all the exposed surface.
- On-ground experiments to verify the developed material and to size the cooling system
- Correlations with thermo-mechanical FEM simulations
- Expected lower thermal distortions and oxidation problems due to lower wall temperature than in non-cooled structures (no coating required)



*c) Metal Matrix Composites, Proposed by AAS-I*

- Fuselage panel in metallic material, reinforced by ceramic long fibers, and with active systems for health monitoring embedded in it.
- On ground experiments to verify and set-up the system.
- Ni-based superalloy or Ni-based intermetallic material
- Withstand thermal spikes between 1000 and 1100°C.
- Coated ceramic fibers
- External coating of the panel against high T oxidation
- Some fibers substituted with hi-T resistant highly transparent material, to monitor the state of the panel
- Extensive mechanical characterization campaign
- Sapphire fibers submitted to mechanical stresses at various temperature to create an experimental data base of stress / monitoring behaviour

*d) Health Monitoring/Management, Proposed by AAS-I and CIRA*

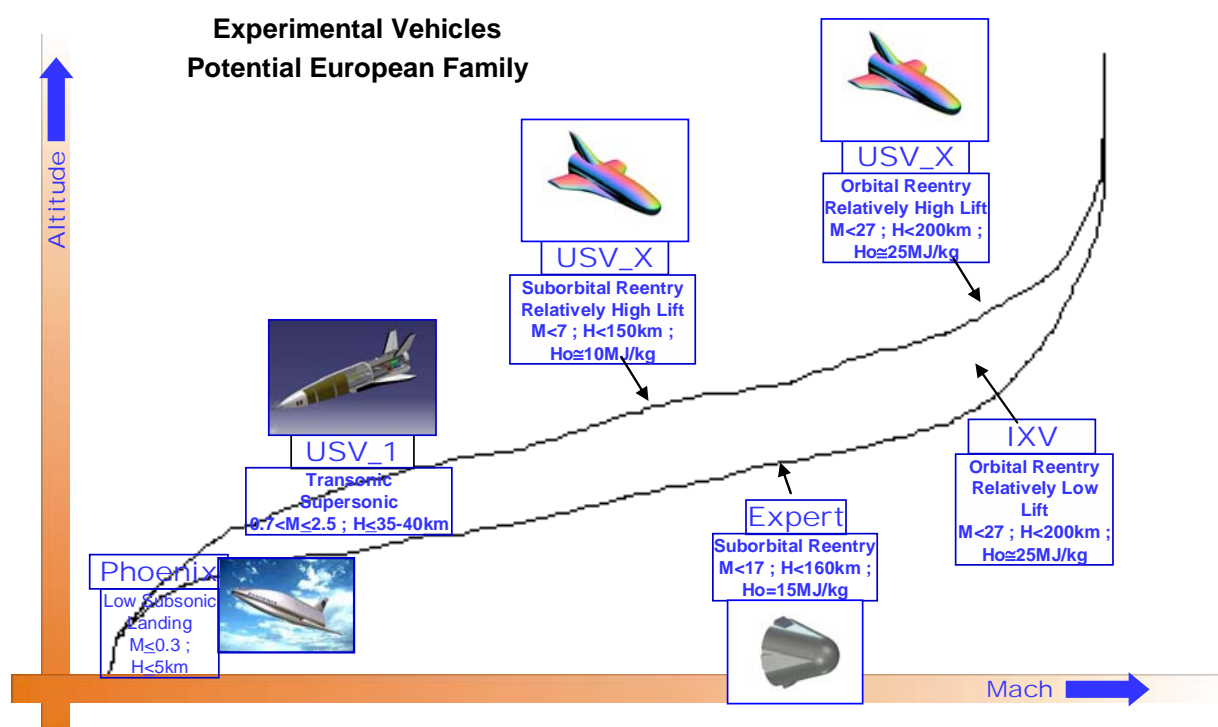
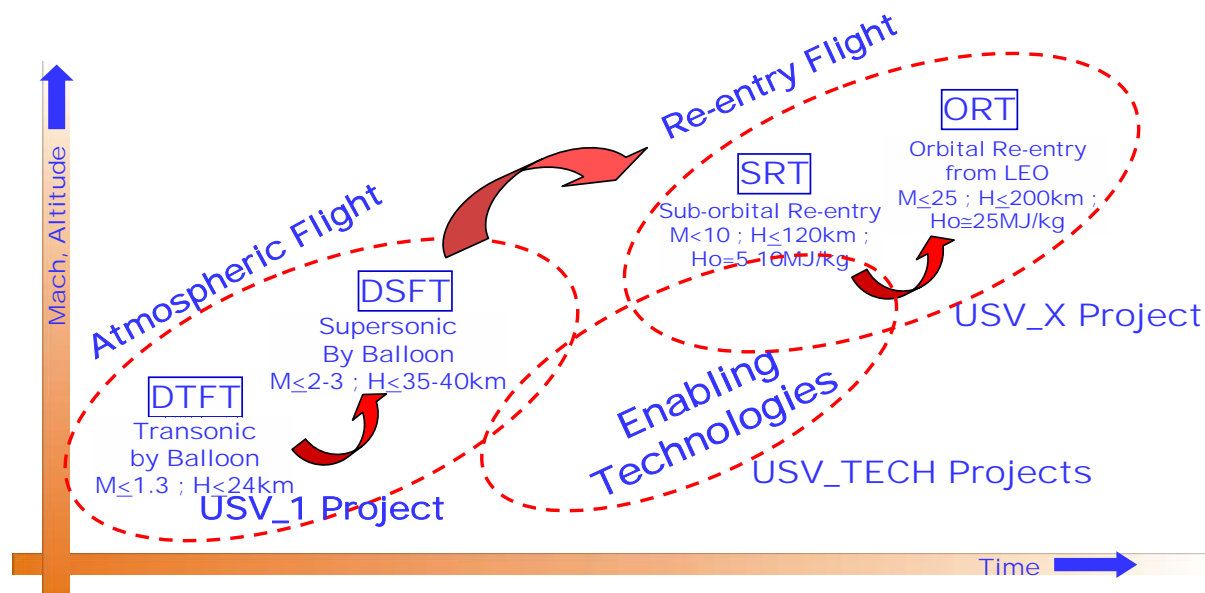
- HM\_M concept includes sensors, data base, data communication, software and algorithms which will be used to manage both the mission and the health of the vehicle with an integration of both ground and flight segment elements.
- The I&IHMS (Intelligent & Integrated HM System) allows to develop and integrate the technologies which can provide a continuous, intelligent and adaptive health state of reusable transportation vehicle, aiming to improve safety and reliability as well as reducing operational costs.
- As experiment, is proposed the on-board evaluation of sonic fatigue
- Fenomena originated by a considerable number of sources of vibrational loads (acoustic, random, re-entry, etc.) affecting the expected operational life of the item before preventive maintenance or, worst case, rupture
- Real-time calculation of expected residual life of the structural item and potential identification of out-of-normal events (and therefore corrective actions)
- As basic experiment, one instrumented structural item is monitored in high frequency band. Frequency answer is monitored and compared with expected behaviour. Residual life can be calculated by dedicated algorithms either on-board or on-ground

*e) Black-out, Proposed by AAS-I and Politecnico di Torino*

- Possible development of payload experimentation as partially developed for EXPERT mission
- Measurement of electron density and RF link attenuation patterns during the complete reentry trajectory via "reflectometry".
- Active (TX / RX) / passive (RX only) mode experiments
- Main on-board elements:
  - RX
  - TX (possibly shared with system TX)
  - antennas (possibly shared with system TX)
  - data processor (possibly shared with system)
  - data storage

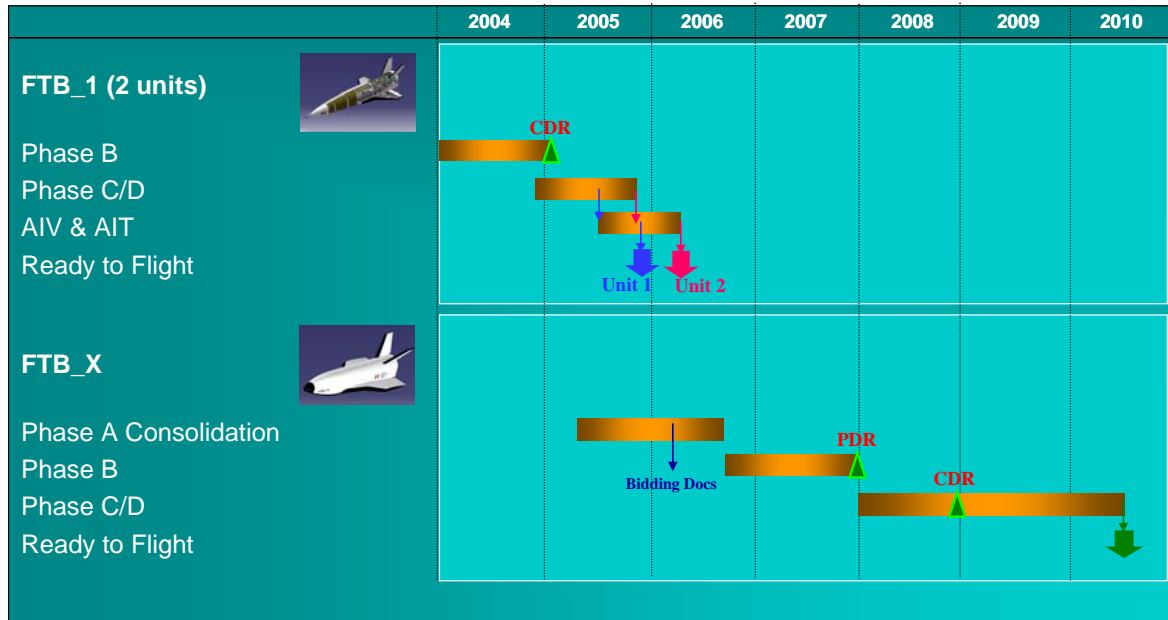


## USV Synoptic

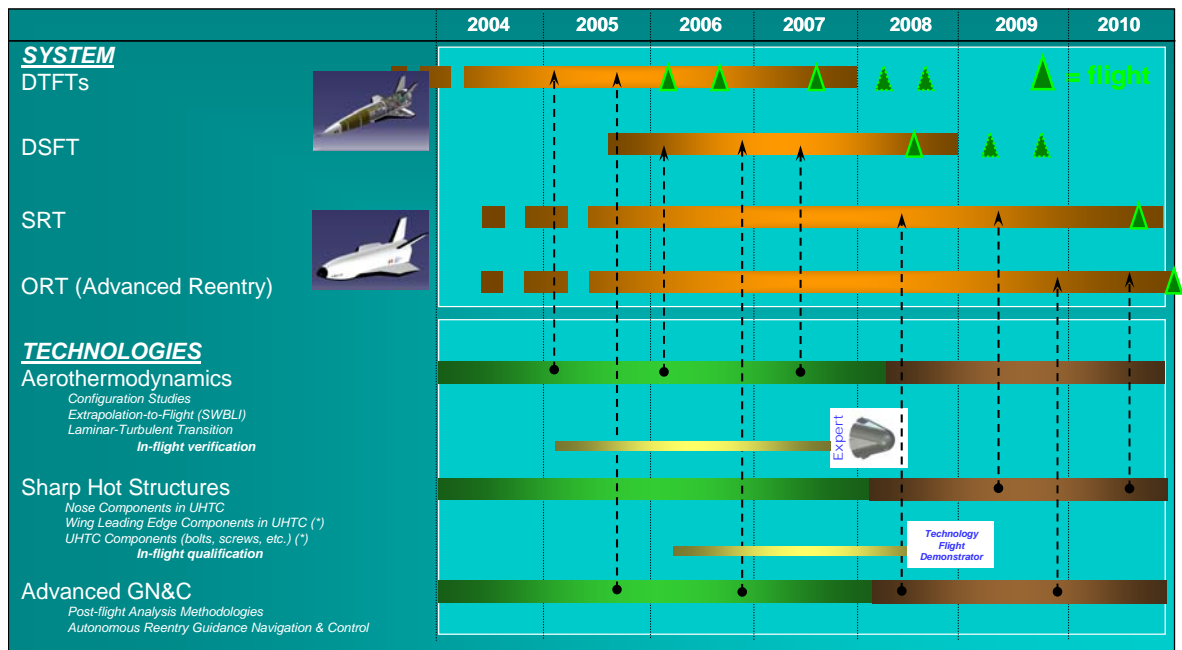


## 4. Flights & Program Schedule

### FTBs PLANNING

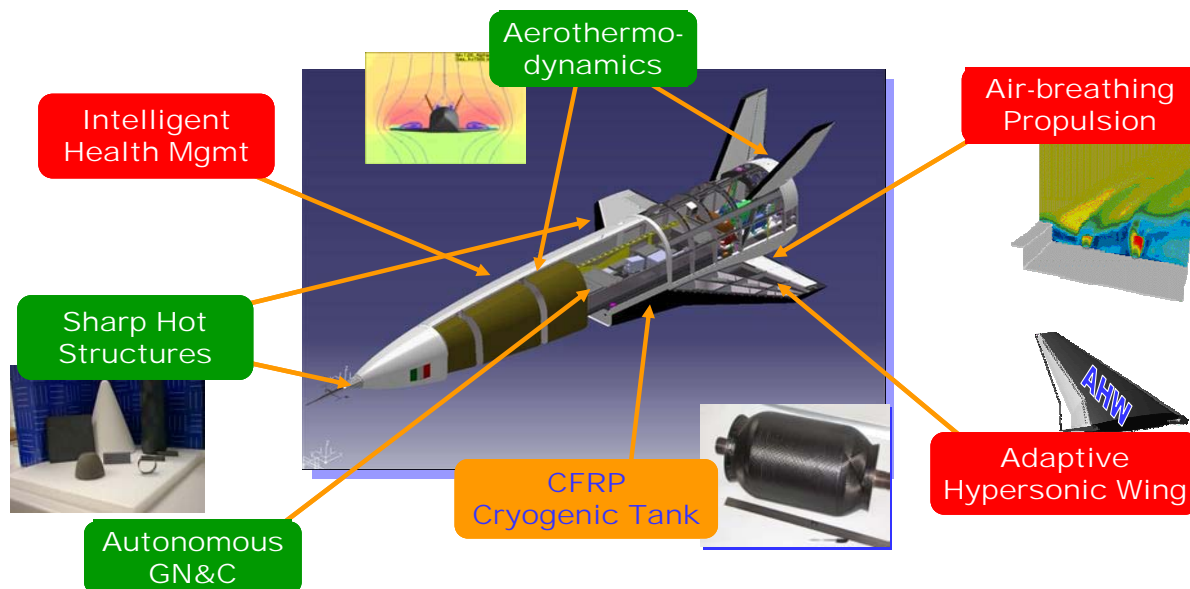


### OVERALL PLANNING



## 5. USV TECH: Technology Projects

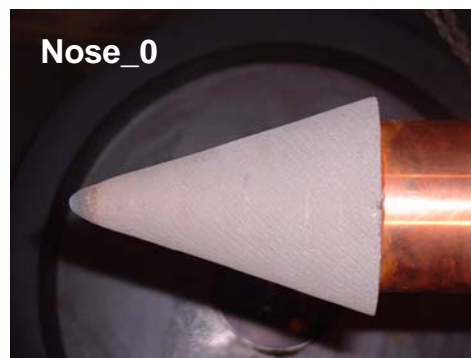
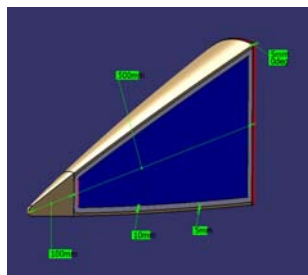
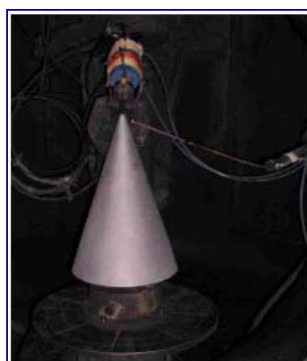
The R&D projects currently in progress aim at the **critical aspects** of the USV FTBs realization, but also at **various themes** connected to the development of future generations reusable systems



### SHS: SHARP HOT STRUCTURES

Design, realise and qualify (both on-ground and in-flight) hot structure components made of innovative ceramics able to operate at temperatures as high as 2000°C.

- ❑ fly on-ground qualified (Scirocco) Nose and WLE on FTB\_X
- ❑ Expert experiment

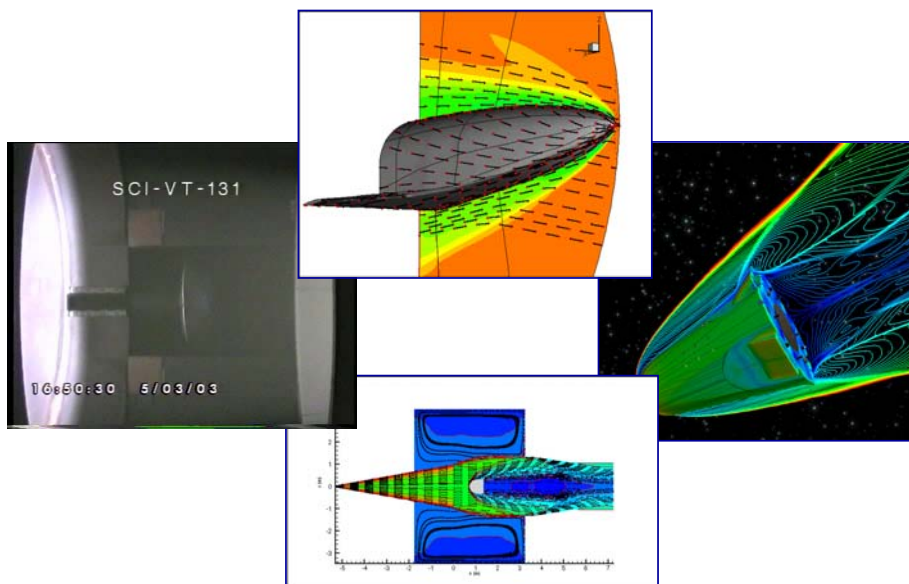




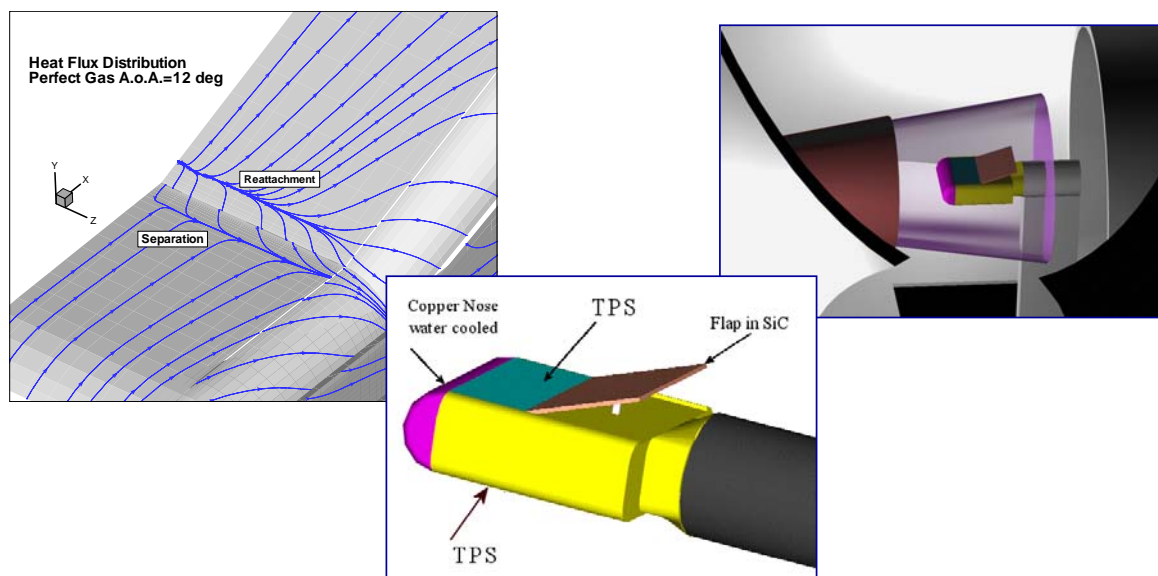
## **CLAE: CONFIGURATION AND LOCAL AEROTHERMODYNAMIC EFFECTS**

Develop innovative design methodology for new aerodynamics configurations; study of laminar-to-turbulent transition; develop know-how for the Extrapolation-to-Flight problem, with specific regard to SWBLI.

- ✦ fly experiments on Expert, SRT, ORT



## Shock Wave Boundary Layer Interaction



The three **combined heat flux/pressure sensors** on the PM1000 region are RAFLEX sensors (to be verified).

**Pressure measurements** points are about 20 included those foreseen in the RAFLEX sensors.

**Heat flux sensors** in the cooled nose region shall be three, if possible.

The **thermocouples**, that have the role of cross check with I/R thermography measurements, shall be in number of about 5-6 (type K in the PM1000 and type S or C in the C/SiC region).

The **I/R thermography** system, in addition to the temperature map, shall be also used as diagnostic technique to derive a heat flux distribution.

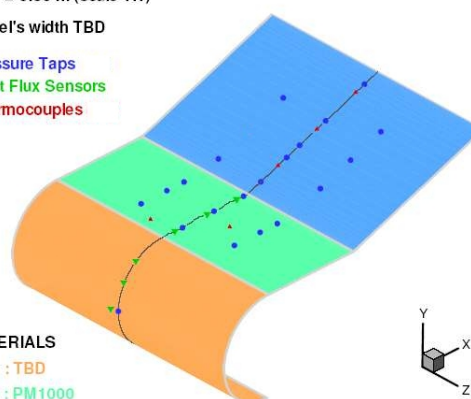
A **micro-pyrometer** will be added, if possible, in the cavity under the flap.

$R_{nose} = 0.10 \text{ m}$   
 $L_{plate} = 0.20 \text{ m}$   
 $L_{flap} = 0.30 \text{ m (scale 1:1)}$

model's width TBD

Pressure Taps  
Heat Flux Sensors  
Thermocouples

MATERIALS  
Nose : TBD  
Plate : PM1000  
Flap : C-SiC

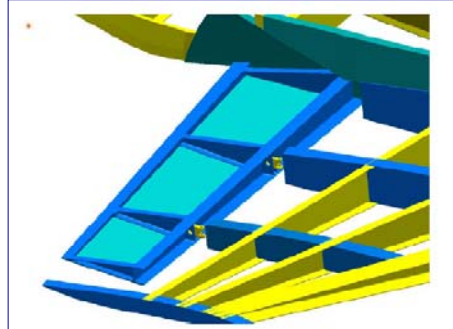
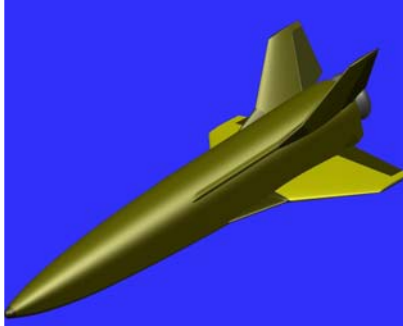


PWT Model Instrumentation

## GNC: AUTONOMOUS GNC

Develop innovative and autonomous GNC systems by means of Rapid Prototyping techniques for both low Mach number flight of DTFT/DSFT and reentry phase of SRT/ORT.

- fly GNC experiments on all USV missions



## 6. Conclusions

USV is a fundamental seed for the development of several possible future Space Transportation Systems ranging from advanced capsules to winged vehicles, from more classical reentry body to advanced hypersonic flying concepts, from civil to military applications.

